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EFFECT OF ZIRCONIUM ADDTION ON CORROSION RESISTANCE OF ALUMINUM – BRONZE ALLOYS IN (3.5%NaCl AND 2M HCl) SOLUTIONS

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ABSTRACT

The aim of this work is to study the effect of zirconium alloying element (0.5, 1, 1.5 and 2 wt%) on corrosion resistance of Aluminum bronze alloy in (3.5% NaCl and 2M HCl) solutions. Casting of aluminum bronze alloys was done with 15 wt % Al, using gas furnace and steel mold under inert atmosphere of argon. Homogenization heat treatment at 500 ºC for 4 hours was accomplished for ingot alloys. Light optical microscope was used for microstructure observation. Electrochemical tests (OCP – Time measurement and potentiodynamicpolarization)in (3.5% NaCl and 2M HCl) solutions were used for corrosion resistance assessment of Aluminum bronze alloy. Zirconium addition moved the OCP toward the negative direction, which makes the alloy less noble, whereas zirconium addition improves corrosion resistance by decreasing corrosion current density. The improvement percentage range is (54.5 – 71.2%) in NaCl solution and (68.8-97.1%) in HCl solution, the best improvement percentage is for 1% Zr in both solutions.

KEYWORDS: Corrosion Resistance, Aluminum Bronze, Zirconium, NaCl & HCl

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Original Article

1. INTRODUCTION

Aluminum bronzes have high strength and corrosion resistance, which make these alloys possess a wide range of applications such as marine, offshore and under adverse environment e.g. (aerospace, automotive and petrochemical industries) [1,2,3]. Aluminum bronze alloys have several alloying elements, the main one is aluminum. Iron, magnesium, nickel, tantalum, manganese and silicon are the alloying elements which may be used with aluminum bronze alloys in different amount. The role of each element is as follows: Aluminum increases strength and oxidation resistance, iron, magnesium and tantalum increase strength and improve microstructure, nickel and manganese enhance corrosion resistance and iron refines the grains [4, 5, 6]. The aim of this work is to study the effect of zirconium alloying element with different percentages (0.5, 1, 1.5 and 2%) on corrosion resistance of Aluminum bronze alloy in (3.5%NaCl and 2M HCl) solutions.

2.EXPERIMENTAL PROCEDURE

2.1 Alloys and Specimens Preparation

Gas furnace was used to cast aluminum bronze alloys under inert atmosphere of argon gas using steel mold (11.5 mm diameter and 25 mm height). The metals used in this work are (Cu, Al and Zr) with high purity of ((99.7, 99.9 and 99.9 %, respectively). The composition of the base aluminum bronze alloy is (85% Cu and 15% Al), zirconium was added in the following percentages(0.5, 1, 1.5 and 2 wt %). Homogenization heat treatment at 500 ºC for 4 hours [7] was accomplished todistribute elements and phases, uniformly. The dimension of the specimens is 11.5 mm in diameter and 2mm in thickness.Table (1) shows code and chemical composition of specimens used in this work.

Table 1: The Chemical Composition of Aluminum Bronze Alloys

Alloy Code	Cu	Al	Zr
M	85	15	-
A	84.5	15	0.5
B	84	15	1
C	83.5	15	1.5
D	83	15	2

2.2 Microstructure Observation

Microstructure Observation and studying of aluminum bronze alloys were done using light optical microscope, wet grinding with grades of (600, 800, 1000 and 2000), and polishing with diamond paste (1µm particle size) was accomplished for the specimens. The composition of etchant solution used is shown in Table (2) [8].

2.3 Electrochemical Test

Two types of electrochemical tests (Open Circuit Potential (OCP) – time measurements and potentiodynamic polarization) were carried out to assess the corrosion resistance of aluminum bronze alloys, by using two different solutions (3.5 % NaCl and 2M HCl). The OCP measured with respect to saturated calomel electrode (SCE), with interval of five minutes, when potential reached nearly constant value, the test was finished. Potentiodynamic polarization was accomplished according to ASTM standard (G5 – 87) [9] by using computerized potentiostate (type DY2323 Bi-Potentiostat, USA). The electrodes used (reference electrode and Auxiliary Electrode) are SCE and platinum, respectively. It (±250 mV) is the range of polarization test with respect to OCP; the scanning rate is 1mV/Sec. The following equation was used for corrosion rate calculation [10, 11]:

$$\text{Corrosion Rate (mpy)} = \frac{0.13\ i_{corr}(E.W.)}{A.\rho} \quad (1)$$

Where:

E.W. = equivalent weight (g/eq.).

A = area (cm2).

ρ = density (g/cm2).

0.13 = metric and time conversion factor.

icorr = current density (µA/cm2).

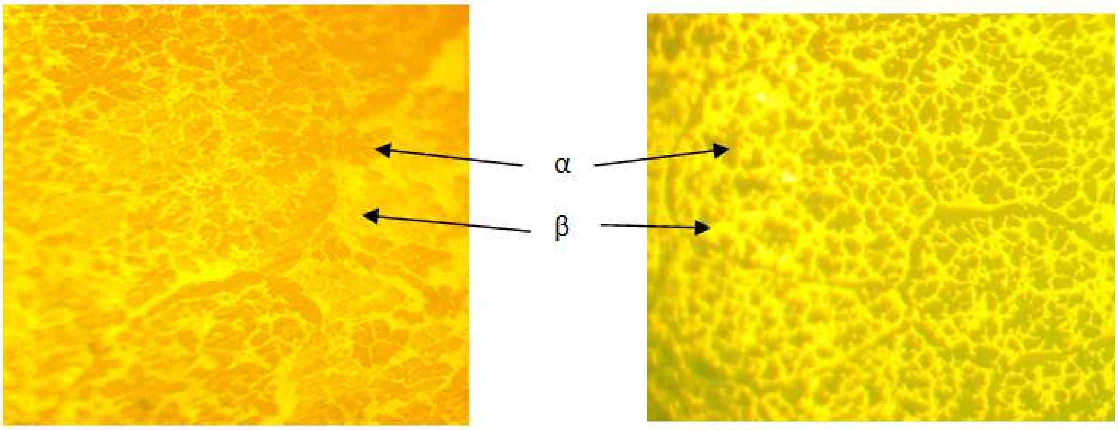
Table 2: The Composition of Etchant Solution for Aluminum Bronze Alloys [8]

No.	Constituent	Quantity
1	$FeCl_3$	8g
2	HCl	25 ml
3	H_2O	100

3. RESULT AND DISCUSSIONS

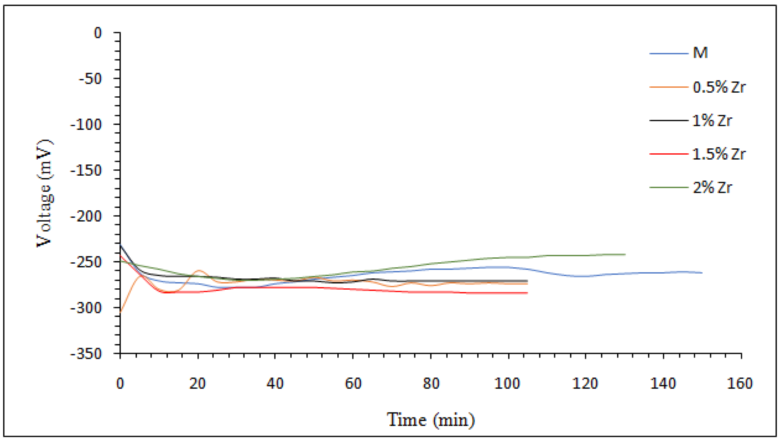
Figure (1) shows the Microstructure of homogenized aluminum bronze alloys. The matrix is β phase (white) and (α phase) light gray, which is distributed in the matrix that is observed in the standard microstructure [12]. Zirconium additions will be at grain boundaries and refine α phase grains.

The OCP – time measurement is illustrated in figure (2). In case of 3.5% NaCl solution, the test duration time is(105 – 150) minutes, the OCP starts with (-231, -305, -233, -244 and -249) mV for aluminum bronze alloys (M, A, B, C and D) respectively, from figure (2-A). It can be noted that the potential move to negative direction is due to the continuous dissolution of the alloys. When dissolution and deposition are in equilibrium, the OCP will be nearly in constant value.The reported OCP for aluminum bronze alloys (M, A, B, C and D) are (-262, -274, -271, -284 and -242) respectively, and for 2M HCl solution, the test duration time is (120 – 170) minutes. The OCP starts with (-193, -245, -268, -245 and -213) mV for aluminum bronze alloys (M, A, B, C and D), respectively. Figure (2-B) illustrates the behavior of OCP of alloys, where the potentials move towards the negative direction, which is the same behavior of the alloys in the 3.5% NaCl solution. The recorded OCP for aluminum bronze alloys (M, A, B, C and D) are (-280, -318, -341, -354 and -275), respectively. Zirconium additions move the OCP of the aluminum bronze alloys towards the negative direction (less noble), except at 2% Zr addition, where there is a slight improvement in OCP (towards positive direction) (7.6% in NaCl solution and 1.7% in HCl solution).Therefore, it is recommended to increase zirconium percentage more than 2%, to investigate which percentage can increase alloy nobility, considerably.

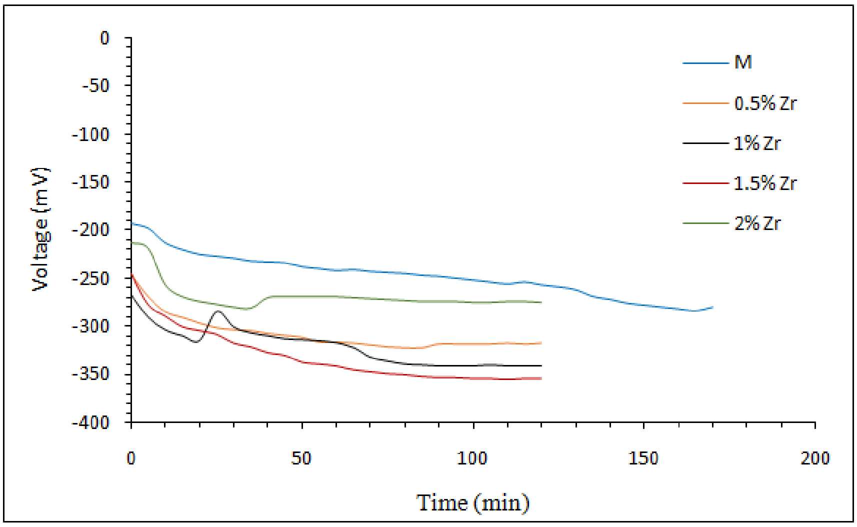


(M) (D)

Figure 1: Microstructure of Aluminum Bronze Alloys (M & D). (600X)



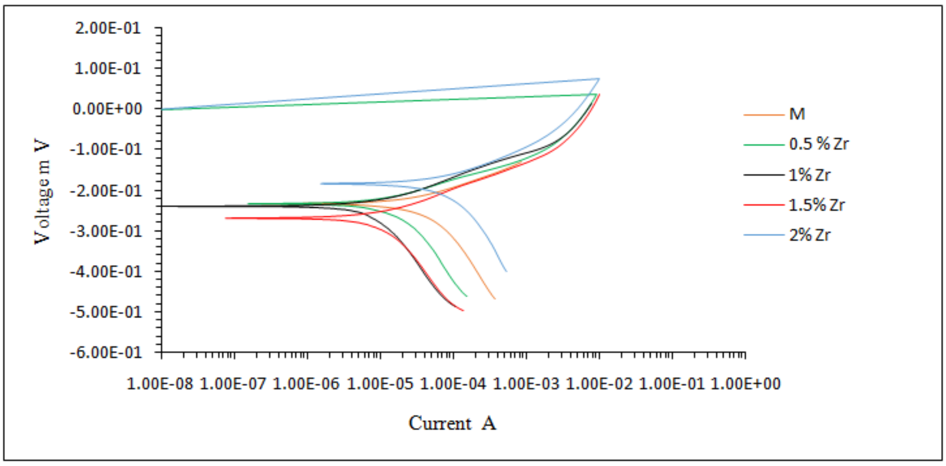
(A)



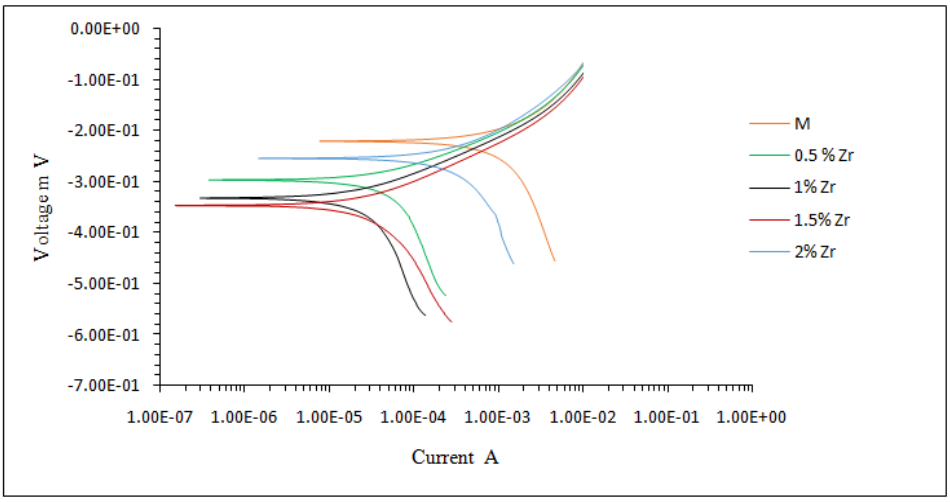
(B)

Figure 2: Open Circuit Potential – Time of Aluminum Bronze Alloys in A: 3.5% NaCl Solution, B: 2M HCl Solution.

Figure (3) (A &B) illustrates polarization tests of aluminum bronze alloys in 3.5% NaCl and 2M HCl solutions. In case of 3.5% NaCl solution, Table (3) shows the obtained corrosion parameters (Ecorr, Icorr, and corrosion rate) of aluminum bronze alloys (M, A, B, C and D).The polarization test starts with cathodic polarization, where current density decreases with increasing potential, as potential reachesEcorr, with increasing potential active anodic polarization will start, at which, the current density increases with increasing potential due to the dissolution of aluminum bronze alloys as mentioned in many studies[1-5]. The obtained corrosion current density (Icorr) for aluminum bronze alloys (M, A, B, C and D) are (37.87, 17.21, 10.96, 12.61 and 78 µA/cm2), respectively, as shown in Table (3). It can be noted that there is decrease in (Icorr) with increasing zirconium content, and thus increasing corrosion resistance (decreasing corrosion rate), but when zirconium percent reaches 2 wt%, corrosion current density will increase considerably to reach value more than that of base aluminum bronze alloy (M). The corrosion rate of aluminum bronze alloys are (20.41, 9.29, 5.87, 6.73 and 41.54 mpy), respectively. As mentioned above, the improvement percentage in corrosion rate range is (54.5 – 71.2%), the zirconium addition 1% Zr was the best one, as shown in figure (4-A).When polarization tested in 2M HCl solution, the table (4) shows the obtained corrosion parameters of aluminum bronze alloys, similar to polarization test in NaCl solution. The current density decreases with increasing potential, until reachesEcoor, with increasing potential active anodic polarization started. The corrosion current density (Icorr) for aluminum bronze alloys (M, A, B, C and D) are (912.52, 53.13, 26.59, 30.77 and 287.66 µA/cm2), respectively. It can be noted that there is decreasing corrosion current density (Icorr) with increasing zirconium content,which indicates decrease of alloys dissolution (corrosion resistance improvement). The corrosion rate of aluminum bronze alloys is (491.99, 28.69, 14.251, 16.437 and 153.194 mpy), respectively. Zirconium additions led to improve corrosion resistance, the improvement percentages of aluminum bronze alloys (A, B, C and D) are (94.1, 97.1, 96.6 and 68.8%) respectively. The best zirconium addition was 1wt %, as shown in Figure (4-B).



(A)



(B)

Figure 3: Polarization Curves of Aluminum Bronze Alloys in A: 3.5% NaCl solution: 2M HCl solution

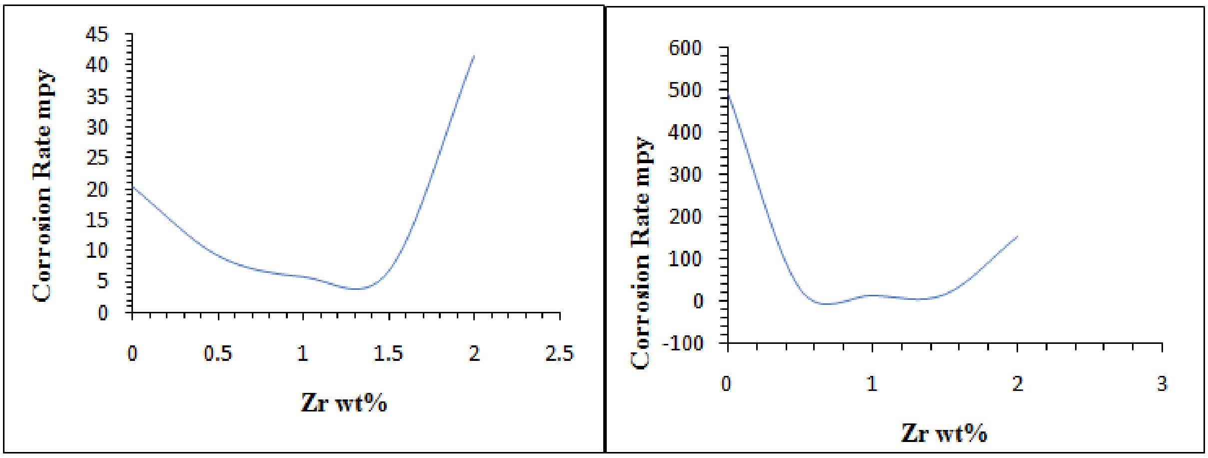
Table 3: The Corrosion Potential, Corrosion Current Density, Corrosion Rate and Improvement Percentage of Aluminum-Bronze Alloys in 3.5% NaCl Solution

Alloy	E_{corr} (mV)	I_{corr} ($\mu A/cm^2$)	Corrosion Rate (mpy)	Improvement Percentage %
M	-234	37.87	20.41	-------
A	-233	17.21	9.29	54.5
B	-240	10.96	5.87	71.2
C	-289	12.61	6.736	67
D	-184	78	41.54	0

Table 4: The Corrosion Potential, Corrosion Current Density, Corrosion Rate and Improvement Percentage of Aluminum Bronze Alloys in 2M HCl Solution.

Alloy	E_{corr} (mV)	I_{corr} ($\mu A/cm^2$)	Corrosion Rate (mpy)	Improvement Percentage %
M	-220	912.52	491.99	-------
A	-296	53.13	28.69	94.1
B	-332	26.59	14.251	97.1

Table 4: Contd.,				
C	-347	30.77	16.437	96.6
D	-254	287.66	153.194	68.8



(A) (B)

Figure 4: The Relationship between Corrosion Rate (mpy) and Zirconium Percentage (%) in A: 3.5% NaCl Solution,B: 2M HCl Solution

4. CONCLUSIONS

- Zirconium addition to the aluminum bronze alloys made the open circuit potential more negative, so the alloys are less noble.
- The 2 wt % Zr addition shifts the OCP to positive direction, increasing the potential nobility with 21.3%.
- Zirconium addition decreases the corrosion current density, and consequently increasing corrosion resistance.
- Improvement percentage in corrosion resistance due to zirconium addition ranges from (54.5 – 71.2%) in 3.5% NaCl solution and (68.8- 97.1%) in HCl solution.

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Dr. Haydar H. J. Jamal Al-Deen, currently working as Assistant Professor in Department of Metallurgical Engineering, Materials Engineering, Faculty at University of Babylon, Iraq. He did his B.Sc. Production Engineering at University of Technology in Iraq(1992), M.Sc. Metallurgical Engineering at University of Technology in Iraq(1998), The title of thesis is (Erosion Resistance Improvement of 70-30 Brass by Trace Additions of Some Elements(Ge, Te, Al)), Ph.D. Metallurgical Engineering/ University of Technology/Baghdad/Iraq(2008), The title of thesis is (Improvement of Mechanical and Corrosion Properties ofDental Amalgam Alloys). He has contributed in publish of more 7 articles in national and international journals. His research work is about corrosion resistance in alloys and study and improvement of biomedical application metallic alloys.He isone of staff member of Materials Science Faculty- University of Babylon, Iraq. And I have three PhD students and nine MSc. Students.